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METHOD AND APPARATUS FOR EXTERIOR AND INTERIOR GRINDING OF A ROTATIONALLY SYMMETRICAL MACHINE PART PROVIDED WITH A LONGITUDINAL BORE

The invention relates to a method for grinding a rotationally symmetrical machine part provided with a longitudinal bore, the one end-face surface of which is embodied as an active surface in the form in particular of a flat truncated cone with a cross-section with a straight or curved contour, in accordance with the preamble to claim 1.

The machine parts to be ground with this method are present for instance in transmissions with continuously variable gears, as are needed in motor vehicles. Two machine parts oppose one another with active surfaces facing one another. The active surfaces thus form an annular space with a nearly wedge-shaped cross-section in which a tension member such as for instance a chain or a belt moves in and out between different radii depending on the distance from the active surfaces. Since such a transmission must work very precisely and transmit large torques, high demands are placed on the dimensional stability and surface quality of the machine parts. This also applies to the associated grinding procedures, in particular when grinding the active surface.

In accordance with the prior art known from commercial practice, the method cited in the foregoing has been performed in single operations, that is, in a plurality of clampings. The active surface is ground by means of corundum grinding wheels using the angular infeed grinding method. For interior cylindrical grinding of the longitudinal bore located on the machine part, the machine part must then be clamped in another machine, where the internal cylindrical grinding of the bore wall can occur using an appropriate small grinding wheel.

The known method has a number of disadvantages. First, it requires grinding wheels with a conical shape or with a highly graduated diameter, which are difficult to manufacture and dress. In such grinding wheels with circumferential regions of very different diameters, the circumferential speeds of the regions to be ground are also different. This means that the critical cutting speed at the

grinding location must be different and therefore cannot be optimal over all. The result of this is regions of varying roughness, which has a negative effect on the active surface. Finally, there are also problems involving cooling by means of the conventional emulsions and grinding oils. That is, during angular infeed grinding a narrowing wedge occurs at the grinding location, and coolant/lubricant cannot be fed to it optimally. The result is thus uneven cooling of the grinding location. All of these difficulties can be traced back to the fact that the aforesaid known method has in the past been performed with corundum grinding wheels, which have a significantly shorter service life and must be dressed more frequently than CBN grinding wheels, which have since come into wide use.

DD 143 700 concerns an apparatus for grinding tungsten plates that are used for instance as rotating electrodes in x-ray tubes. According to the drawing, such a tungsten plate has the contour of a truncated cone in which the incline of the surface line is approximately 30° relative to the base. In this known apparatus, the tungsten plate is clamped in a workpiece holder that is pivotable about an axis perpendicular to the apparatus frame. Situated opposing the workpiece holder is a longitudinal support that is displaceable in the horizontal plane. Arranged on the longitudinal support is a compound slide rest that carries a grinding spindle for driving a small cylindrical grinding wheel that acts for internal grinding of a bore in the tungsten plate. Separated from this compound slide rest, the longitudinal support furthermore carries a rigid electrogrinding spindle for driving a conical grinding wheel. One end face and the cone envelope-shape region of the tungsten plate are to be ground with the conical grinding wheel. For this, the conical grinding wheel and the tungsten plate must be brought into the correct position relative to one another by pivoting the workpiece holder, displacing the longitudinal support, and using manually actuated advancing controls.

Nothing other than angled grinding in the region of the cone envelope can be taken from DD 143 700. The known apparatus, which must in part be operated manually, is difficult to operate and requires some skill.

Known from EP 1 022 091 A2 is a tool machine for grinding workpieces in which two cylindrical

grinding wheels of different sizes are situated on one turret that is itself arranged on a displaceable slide. By pivoting the turret 180°, the two grinding wheels can be selectively brought up against different regions of a rotationally symmetrical workpiece. The workpiece is arranged in a workpiece receiver that is itself displaceable in the longitudinal direction of the workpiece. For grinding, the workpiece is caused to rotate. In addition, in this known workpiece machine the workpiece receiver can be adjusted about an angle of +/- 30° inclined to the displacement direction of the workpiece receiver. EP 1 022 091 A2 does not explain how grinding should proceed when the workpiece receiver is in an angled position. However, since pivoting of the turret carrying the grinding wheel is expressly indicated in increments of 90°, it is obvious that with this known tool machine, as well, longitudinal grinding with one grinding wheel is intended when conical exterior contours with significant angles of inclination in the cone are to be ground.

In contrast to this, the object of the invention is to provide a method of the type cited initially in the foregoing with which the processing time can be decreased and a better grinding result can still be obtained.

The same object applies correspondingly for the apparatus claimed in claim 7.

This object is attained in accordance with the method steps listed in the characterizing portion of claim 1 in that first the active surface on the machine part held on one side at its exterior circumference is ground, the rotating circumferential contour of the first cylindrical grinding wheel being positioned perpendicularly against the active surface, the machine part being displaced in the direction of its rotational and longitudinal axis relative to the first grinding wheel, whereby the axial extension of the first grinding wheel covers the radial angled extension of the active surface, and in that then in the same clamping the interior wall of the longitudinal bore is ground, a second grinding wheel of smaller diameter being introduced into the longitudinal bore of the machine part by pivoting a grinding headstock, which carries at least the first and the second grinding wheel, and positioned radially against the interior wall.

Thus in the inventive method the machine part to be ground remains in a single clamping in which all of the grinding procedures are undertaken. This is made possible in that first a first cylindrical grinding wheel is placed perpendicularly against the active surface and then a second cylindrical grinding wheel of smaller diameter is inserted into the longitudinal bore of the machine part and placed radially against the interior wall. The options for using two different grinding wheels on different processing surfaces of one and the same workpiece are known in general to one skilled in the art.

One special feature with the inventive solution is that the first grinding wheel is placed perpendicularly at its rotating circumferential surface against the active surface that runs on an incline, whereby the axial extension or the width of the first grinding wheel covers the radial angular extension of the active surface.

Thus the active surface is ground with the cylindrical circumferential surface of the grinding wheel using the vertical grinding method, whereby positioning is effected by mutual relative displacement.

A uniform cutting speed across the entire width of the grinding wheel results as an advantage. This ensures improved surface quality and surface structure. In addition, optimized dressing parameters are obtained when dressing the grinding wheel because when dressing the same parameters, namely, identical dressing speed, is attained as when grinding, as are the same revolutions per minute and advance values. Because the cutting speed of the grinding wheel remains the same across the active surface, the attainable surface roughness also remains the same. Optimum values for cutting volume per unit of time can also be attained using the same cutting speed of the grinding wheel across the entire conical surface.

This is not the case for angular infeed grinding. Given an exterior diameter of the conical active surface, if one assumes a value of for instance 190 mm and an adjacent mean diameter (in the region of the longitudinal bore) on the active surface of 40 mm, the workpiece speed changes by a factor

of 4.75 because of the rotation of the workpiece during grinding. The height of the conical surface is thus approx. 75 mm.

Given an assumed diameter of the corundum grinding wheel of 750 mm, the cutting speed at the exterior diameter of the conical surface is then approx. 80% of the cutting speed of the grinding wheel at the smallest diameter of the conical surface. This opposes the cutting volume, because it is highest at the greatest diameter on the conical surface. This means that because of the grinding wheel placed perpendicular to the conical surface, the ratio of cutting speed to cutting volume that has to be carried across the conical surface is substantially improved.

Furthermore, significantly improved conditions when cooling the grinding zone result because practically these same conditions occur when grinding the active surface as during vertical grinding, so that there is a uniformly narrow cooling zone to which it is easy to feed the coolant/lubricant and which it also exits rapidly as well.

Overall such advantages result that the inventive grinding method can be best performed with ceramic bound CBN grinding wheels. Overall there is clearly a reduced number of cycles on modern processing machines with simultaneously substantially improved grinding results.

Fundamentally it would be possible for the first grinding wheel to be placed against the active surface of the machine part to be ground in the strictly radial direction in that the first grinding wheel is moved transverse to its longitudinal extension and in the angled direction to the machine part. In this case the machine part would have to be arranged at a position of the associated machine bed that remains the same. However, the apparatus required for performing the method is simpler when in accordance with the inventive method positioning occurs in that the machine part is displaced in the direction of its rotational and longitudinal axis relative to the first grinding wheel. From this movement, only an angled component falls on the grinding site on the active surface, but it [angled component] deviates by only a small amount from the direction of the longitudinal axis so that there is nearly still vertical grinding in the conventional sense. A lower force component results in the

radial direction of the active surface so that the running surface can be worked with optimized advancing during grinding. This also reduces the grinding time, and improved accuracies in the grinding condition of the active surface still result.

The subsequent interior grinding of the longitudinal bore can be undertaken using longitudinal grinding. The procedure for peel-grinding, in which grinding is performed directly to the final diameter, also comes into consideration. However, it is also possible for the interior wall of the longitudinal bore to be ground using infeed grinding.

The latter method is particularly considered when in accordance with another advantageous method variant individual axial segments of the interior wall of the longitudinal bore are ground.

In a further design of the inventive method, at least three grinding wheels are provided that are brought into their working position by pivoting three grinding spindles that carry the grinding wheels. Additional grinding procedures can be performed using the method expanded in this manner, or for instance interior cylindrical grinding can also occur in the conventional steps of pregrinding and finish grinding.

Finally, it is not mandatory to follow the sequence in which first the active surface of the machine part and then the interior wall of the longitudinal bore is ground. Fundamentally the reverse sequence is also possible. One skilled in the art of grinding will establish the sequence of procedures depending on the design of the machine part, because the amount of heating during grinding and the type of clamping are important.

In accordance with claim 7, the invention also relates to an apparatus for grinding a rotationally symmetrical machine part of the type cited in the foregoing in connection with the method. In an apparatus for grinding a rotationally symmetrical machine part provided with a longitudinal bore, the one end-face surface of which is embodied as an active surface in the form of a flat truncated cone with a cross-section with a straight contour, in particular for performing the method in

accordance with any of claims 1 through 6,

- with a clamping device for one-sided clamping of the machine part at its exterior circumference and for rotationally driving it,

- with a grinding spindle slide that can be moved in a direction running transverse to the rotational and longitudinal axis of the machine part,

- with a device for longitudinal displacement of the machine part in the direction of its rotational and longitudinal axis,

- with a grinding headstock that is attached to the grinding spindle slide via a pivot axis running perpendicular to the displacement plane of the grinding spindle slide and that carries at least two grinding spindles that can be pivoted into the working position,

- with a first cylindrical grinding wheel, arranged on the first grinding spindle and driven thereby, that is for vertical grinding of the active surface situated on the machine part and that has an axial extension that is larger than the radial angled extension of the active surface,

- and with a second cylindrical grinding wheel, arranged on the second grinding spindle and driven thereby, that has a smaller diameter than the first grinding wheel and that is for interior cylindrical grinding of the longitudinal bore of the machine part,

- whereby depending on the pivot position of the grinding headstock either the rotating circumferential surface of the first grinding wheel is placed on the active surface of the machine part to be ground or the axis of the second grinding wheel runs spaced from and parallel to the rotational and longitudinal axis of the machine part.

If when this apparatus is operated the method described in the foregoing is used, first the grinding spindle slide is moved in the correct manner to the clamped machine part and the grinding headstock is rotated such that the first grinding spindle, at the cylindrical circumferential surface of the first grinding wheel affixed on it, is placed against the active surface of the machine part. The first grinding spindle must assume an angled position relative to the rotational and longitudinal axis of the machine part that is less than 90°. Then the active surface can be ground by the first grinding wheel using the vertical grinding method, that is, with its known advantages. Subsequently the grinding spindle slide is moved somewhat outward transverse to the rotational and longitudinal axis of the machine part and the grinding headstock situated on the grinding spindle slide is rotated about its pivot axis until the rotational axis of the second grinding spindle with the associated second grinding wheel is approximately in the rotational and longitudinal axis of the machine part. The second grinding wheel is then inserted into the longitudinal bore of the machine part and positioned radially so that interior cylindrical grinding of the longitudinal bore is performed. In this manner all necessary grinding procedures on the machine part are accomplished in one single clamping. However, the prerequisite in every case is a first grinding wheel, the axial extension or width of which is greater than the angled extension of the active surface, because otherwise the vertical grinding method of the active surface, with all its advantages, cannot occur.

One constructive advantageous further development of the inventive apparatus is that in the arrangement of two grinding spindles on the grinding headstock their axes run parallel to one another and the two grinding wheels are attached on the same side of the grinding headstock. In this manner it is possible to change between the two processing procedures with only minor displacement and pivot paths of the grinding headstock.

If additional grinding procedures are to be performed or if one of the individual procedures is to be performed in a plurality of steps, it can be advantageous when in accordance with another embodiment three grinding spindles, each with a grinding wheel, are attached to the grinding headstock at angle intervals of 120° each. Then one of the three grinding spindles is selectively brought into the working position.

Advantageously, the clamping device is a chuck with centrally adjustable clamping jaws and that can also be driven to rotate. Such chucks have proved to be reliable and are known.

In accordance with one additional embodiment, it is advantageous when the clamping device is located on a grinding table that can be moved in the rotational and longitudinal axis of the machine part relative to the grinding spindle slide. The positioning movement when grinding the active surface is then performed in that the grinding table, with the machine part, is moved in the longitudinal direction of the machine part relative to the first grinding wheel.

The invention will be described in greater detail in an exemplary embodiment using the figures. The figures are as follows:

Figure 1 is a view from above onto an inventive apparatus in a first processing phase;

Figure 2 depicts a view corresponding to that in Figure 1 in the subsequent processing phase;

Figure 3 is a section of the machine part to be ground;

Figure 4 explains how the inventive method is performed in the first processing phase;

Figure 5 is the depiction corresponding to that in Figure 4 of the second processing phase.

Figure 1 first provides a schematic illustration of the inventive apparatus with which the inventive method can be performed. A top view of an apparatus for grinding the machine part is shown. Situated on a machine bed 1 is a workpiece headstock 2. It is provided with a chuck 3 that is driven to rotate and on which are situated four clamping jaws 4 that are centrally controlled. The machine part to be ground, labeled 5, will be described greater detail below.

The workpiece headstock 2 has a longitudinal axis 6 that is also the rotational axis of the chuck 3. When the machine part 5 is clamped in the chuck, the rotational and longitudinal axes of the workpiece headstock and the machine part 5 coincide.

In the exemplary embodiment illustrated, the workpiece headstock 2 is affixed to a grinding table 7. Together with the workpiece headstock 2, the grinding table 7 is moved in the direction of the longitudinal axis 6, which is also the conventional Z-axis in the context of a CNC control.

Furthermore situated on the machine bed 1 is a grinding spindle slide 9 that can be moved by means of a displacement motor 8 in a direction transverse to the longitudinal axis 6 of the workpiece headstock 2. On the grinding spindle slide 9, a grinding headstock 10 is pivotably arranged about a pivot axis 11. The direction of pivot is indicated by the rotating arrow B. The pivot axis is perpendicular to the grinding spindle slide 9 and will normally run vertically.

A first grinding spindle 12 and a second grinding spindle 13 are situated on the grinding headstock. The rotational and drive axes of the two grinding spindles are parallel. A first grinding wheel 14 is affixed to the grinding spindle 12. The grinding spindle 13 is fitted with a second grinding wheel 16 that is affixed to a grinding arbor 15. As Figure 1 clearly indicates, the first grinding wheel 14 and the second grinding wheel 16 are both arranged on the same side of the grinding headstock 10.

Figure 1 illustrates the first processing phase of the grinding procedure in which the circumferential surface of the first grinding wheel 14 is placed against the active surface of the machine part 5 to be ground.

In contrast, Figure 2 provides the same view, but of the second processing phase in which the axis of the second grinding wheel 16 runs spaced from and parallel to the longitudinal axis 6 of the workpiece headstock 2.

In order to move from the position in accordance with Figure 1 to the position in accordance with Figure 2, first the grinding spindle slide 9 must be moved somewhat outward in the direction of the X-axis, that is, transverse to the direction of the longitudinal axis 6. Then the grinding headstock 10 on the grinding spindle slide 9 can be pivoted about an angle of somewhat more than 90°, whereupon the second grinding spindle 13 with the second grinding wheel 16 assumes the position visible in Figure 2. The pivoting movement is also illustrated by the rotating arrow B in Figure 2.

Figure 3 is an enlarged section of the machine part 5 to be ground. The machine part is rotationally symmetrical to the rotational and longitudinal axis 17. It comprises a hub part 18 and a coned flange 19 and a longitudinal bore 20 passes through its entire length.

The longitudinal bore can be graduated so that it is not necessary to grind its entire length. In general it is sufficient when the longitudinal bore is ground on the axial segments 21, 22, and 23. At its large end-face surface, the coned flange 19 is embodied like a flat truncated cone with a cross-section that has a straight contour.

The machine part illustrated is a conical disk in a continuously variable gear; in its assembled condition, a chain, belt, or the like slides on the active surface 24. Two active surfaces 24 oppose one another; by changing the distance between them, the radius on which the chain or belt slides can be changed, this resulting in different transmission ratios. Thus it is clear how important the entire and careful grinding of the active surface 24 is for the functioning of the finished continuously variable gear.

The machine part illustrated in Figure 3 has a cylindrical clamping surface 25 and a planar stop surface 26 that are for clamping in the aforesaid chuck 3. The clamping jaws 4 enclose the cylindrical clamping surface 25, while the axial stop is provided by the stop surface 26 on the clamping jaws 4. The machine part 5 is thus clamped exteriorly on one side so that the entire end face, which is on the right-hand side in Figure 3, and in particular the active surface 24 are free for

processing. In addition, a small grinding wheel can be inserted into the longitudinal bore 20 for the purpose of interior grinding.

Figure 4 illustrates the first processing phase in which the active surface 24 of the machine part 5 is ground using vertical grinding.

As stated in the foregoing, first the machine part 5 is clamped between the clamping jaws 4 of the chuck 3. The workpiece spindle is then driven to rotate, as a rule by a variable-speed electromotor. With this, the machine part 5 rotates about its rotational and longitudinal axis 17, which is identical to the longitudinal axis 6 of the workpiece headstock 2.

The first grinding spindle 12 with the first grinding wheel 14 is already in the position described using Figure 1. In that the machine table 7 with the workpiece headstock 2 is now displaced to the right in the direction of the Z-axis in Figure 4, the rotating first grinding wheel is positioned against the active surface 24 of the machine part 5. The axial extension 28 of the second grinding wheel 14 is somewhat larger than the radial angled extension of the machine part 5. Thus the entire active surface 24 is ground by the first grinding wheel 14 using the vertical grinding method with the advantages described in the foregoing.

The first grinding wheel 14 is a ceramic bound CBN wheel that provides a long tool life.

Figure 5 depicts the second processing phase, which corresponds to the view in accordance with Figure 2. In the illustration in accordance with Figure 5, the second grinding wheel 16 has already been inserted into the longitudinal bore 20 and is processing the axial segment 21 of the longitudinal bore 20. The rotational axis of the second grinding wheel 16 is situated spaced from and parallel to the common longitudinal axis 6 of the workpiece headstock 2 and machine part 5. In this phase interior grinding of the segments 21, 22, and 23 of the longitudinal bore 20 is performed, whereby this cylindrical grinding can occur as longitudinal grinding, rough-grinding, or angular infeed grinding.

Legend

1 Machine bed
2 Workpiece headstock
3 Chuck
4 Clamping jaws
5 Machine part
6 Longitudinal axis
7 Grinding table
8 Displacement motor
9 Grinding spindle slide
10 Grinding headstock
11 Pivot axis
12 First grinding spindle
13 Second grinding spindle
14 First grinding wheel
15 Grinding arbor
16 Second grinding wheel
17 Rotational and longitudinal axis
18 Hub part
19 Coned flange
20 Longitudinal bore
21 Axial segment
22 Axial segment
23 Axial segment
24 Active surface
25 Clamping surface
26 Stop surface
27 Line of contact
28 Axial extension